Extracting the Nuclear Caloric Curve from AMD Simulations

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Motivation

- The equation of state describes how temperature, density, composition and energy interact with each other.
- Previous work using ^{70}Zn + ^{70}Zn at 35MeV/u reaction data[1], taken with NIMROD (Neutron Ion Multidetector for Reaction Oriented Dynamics) combined with the Indiana Silicon Sphere[2], showed a relationship between the asymmetry of the nucleus and the temperature. This effect was shown in multiple temperature probes as seen in Figure 2[3,4].
- Antisymmetrized Molecular Dynamics (AMD) model was used with GEMINI++ to generate events for the same system[5,6,7]. These simulated events were then filtered by a software replica of NIMROD.

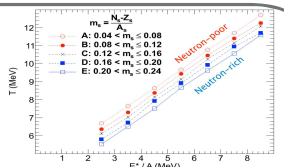


Figure 1: This plot shows the observed caloric curve measured by the proton momentum quadrupole fluctuation (MQF) method as a function of excitation energy per nucleon [3,4].

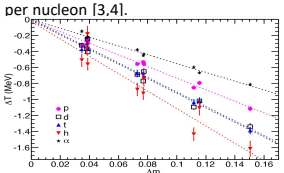
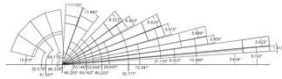


Figure 2: Multiple particles used as temperature probes with the MQF method showed clear asymmetry dependence on the caloric curve[3].

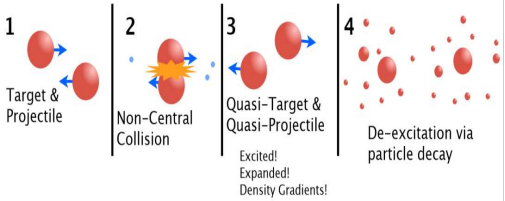
NIMROD Array

Figure(right): NIMROD diagram take from reference [1].



- 4π Silicon Coverage
- Neutron ball gives 4π free neutron multiplicity detection
- Isotopic resolution up Z=17
- Elemental resolution up to projectiles used

Quasi Projectile Reconstruction and Event Selection



The Quasi Projectile (QP) is the highly unstable fragment formed from the projectile immediately after interacting with the target. Figure from reference[8].

Velocity Gates used to assign particles to the QP[8].

$$Z = 1: \quad 0.35 \le \frac{v_z}{v_{z,PLF}} \le 1.65$$
$$Z = 2: \quad 0.40 \le \frac{v_z}{v_{z,PLF}} \le 1.60$$
$$Z \ge 3: \quad 0.55 \le \frac{v_z}{v_{z,PLF}} \le 1.45$$

$$M_n = \frac{M_{meas} - M_{bkg}}{\left(\epsilon_{QP} + \frac{N_T}{N_P}\epsilon_{QT}\right)\left(\frac{\epsilon_{lab}}{\epsilon_{sim}}\right)}$$

The neutron ball was simulated in the code. The neutron multiplicity that was detected was then adjusted in the same way as was done in the physical experiment[9].

Excitation Energy

$$E^*_{QP} = \sum_i^{CP} \frac{3}{2} K_{\perp,i} + M_n \langle K_n \rangle - Q$$

Neutron kinetic energies were calculated from proton kinetic energies with a coulomb correction in both the experiment and the analysis done with AMD.

Event Selection

$$Q = \frac{\sum p_{z,i}^2}{\frac{1}{2}\sum p_{T,i}^2}$$

$$-0.3 \le \log Q \le 0.3 \qquad 48 \le A_{QP} \le 52$$

Events were selected on two conditions:

1. Mass of reconstructed QP was within 48 to 52 nucleons.
2. Log base 10 of the momentum quadrupole was within -.3 and .3 in the frame of the QP.

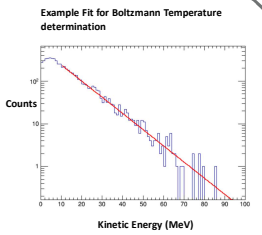
Derived Temperatures

- The two kinetic methods for determining the temperature are slope temperatures, and momentum quadrupole fluctuation (MQF).

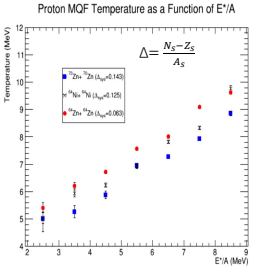
$$Q_{xy} = {p_x}^2 - {p_y}^2$$

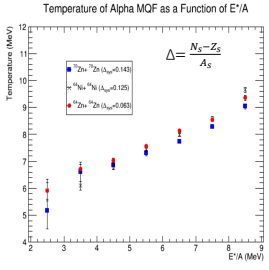
$$\sigma_{xy}{}^2 = 4m^2T^2$$

- The transverse momentum quadrupole is related to the temperature by the above relationship [10].

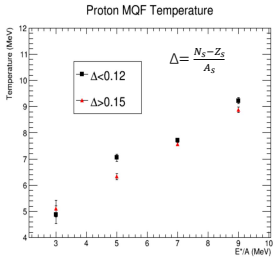


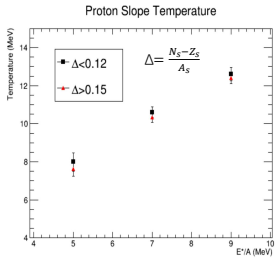
- The slope method calculates the temperature from the slope of the Maxwell-Boltzmann distribution of the kinetic energy.





- In the above left figure the proton MQF temperature extracted from different systems. In the above right figure the alpha particles were used with the MQF method to extract temperatures. The asymmetry effect appears more prominently for the protons.

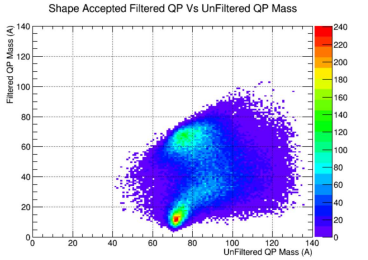




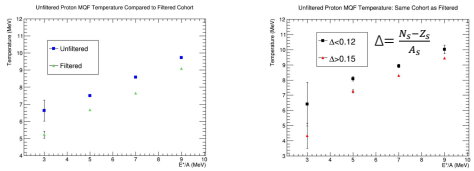
- Temperatures extracted from protons using the MQF using protons for the probe (Left) , and the slope calculated temperature (Right). A weak temperature depression was observed for neutron rich QPs.

Filter Effects

- The same events were both analyzed with the NIMROD filter and without. With no filter applied the free neutrons were then cut out with the Z=1 velocity gate.



- Above: Comparison of the mass of the QP with the NIMROD filter and the shape condition and without the NIMROD filter.



- When events that were accepted by the filtered routine where analyzed without the filter the asymmetry dependence of the caloric curve grew more pronounced (Right). In addition there is a systematic shift in the temperature (Left).

Future Direction

- Analyze different mass regions that have better agreement between filtered and unfiltered. A mass region from 54 to 64 has already been analyzed with the experimental data set.
- Extract densities
- Run more AMD to boost statistics
- Isolate Contamination: start tagging QP, QT (Quasi Target), and QF (Quasi Fusion) particles to isolate contamination. Adjustment of Velocity Gates to lower contamination can then be done.

References

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